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CHARACTERIZATION OF ELECTRIC MATCH INITIATORS BY OUTPUT PERFORMANCE

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The U.S. Army relies on commercial electric matches as an ignition source for a variety of pyrotechnic simulators and training devices. In many instances these matches are sole source and are selected at the beginning of the qualification program for a pyrotechnic item. If the sole source item becomes unavailable or if it is desired to replace it with another, expensive testing has to be undertaken with the pyrotechnic item in order for the substitute to become qualified. If it is determined that the substitute can not replace the original match, then money, effort, and time have been wasted. The purpose of this program was to identify and quantify the characteristics of successful matches in order to base the success of a substitute match on this preliminary inexpensive testing prior to full qualification testing.

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BACKGROUND

The U.S. Army relies on sole source commercial electric matches as an ignition source for a variety of pyrotechnic simulators and training devices. Qualifying alternate products necessitates extensive live item test and evaluation on a case by case basis. This type of testing is expensive because it requires testing with the pyrotechnic device and the match without any assurance that the match will reliably ignite the end item. Therefore, it is essential to test and evaluate the matches prior to installing them in the pyrotechnic item and have a great degree of confidence that, when installed in the item, the item will function as desired. This can only be done if a match exhibits certain output characteristics, which can be identified ahead of time, when testing using recognized testing procedures.

OBJECTIVES

The objective of this project was to establish procedures to characterize the output performance of commercial electric match initiators in support of pyrotechnic munition/ system applications.

SCOPE

The scope of this effort is limited to the establishment of procedures intended to characterize commercially available, electrically initiated, bridge wire (a.k.a., hot-wire) initiators for pyrotechnic munitions/systems including simulators, training devices, signal flares, incendiaries, etc.

TECHNICAL APPROACH

The ICI M103 electric match and the Davey Fire (DF) N55 electric match have been used successfully in many pyrotechnic items. Due to testing cost and availability constraints, these two electric matches were selected for testing as representative samples of "good" matches.

The closed bomb test and the calorimeter bomb test were selected as the two tests which would supply the most meaningful data. The procedures used to conduct the tests are described in this report.

PROCEDURES

Pressure Closed Bomb Test

A laboratory closed bomb system was used to measure the initiation and mechanical energy of the matches. The test specimen (one electric match) was placed in a Coors ceramic crucible cup (6010c), which sat at the bottom of a 50 mL Parr calorimeter bomb. The specimen was initiated by its internal bridgewire, heated by a 10.5 V DC battery under ambient conditions. On firing, a pressure-time trace was recorded with a Nicolet 4094c oscilloscope from a calibrated CEC 0-150 psi strain gage pressure transducer. The collected data were then reduced with a personal computer to generate peak pressure (psi), rise time (ms), specific impulse (psi-ms), burn time (sec), and impetus (ft-lb/lb). The rise time value is the time from 10% of zero pressure to 90% of peak pressure value. Specific impulse is the mechanical energy of the test specimen. The peak pressure is used to calculate impetus which is a measure of the work potential of the composition under constant volume conditions. The following equation shows the impetus in terms of ft-lb of work (energy) per pound of mass:

$$F = 2.307*(P/W)*V$$

where

F =	impetus in ft-lb/lb
2.307 =	conversion constant
P =	peak pressure in psi
V =	bomb volume in cubic centimeters
W =	sample weight in grams

Twenty-five samples of each type of match were tested.

Calorimeter Bomb Test

A Parr 1261 bomb calorimeter system was used to measure the gross heat of combustion of the electric match under constant volume. This system included a calorimeter, a water handling system, a heating/cooling unit, and a data acquisition computer. Each test specimen containing three electric matches was secured in a Coors ceramic crucible. The closed bomb (Parr 1107 semimicro bomb) containing the test specimen was placed in the twin-chambered bucket containing 450 mL of water as a heat sink. The twin chambered bucket sat inside of the outer water jacket which was maintained, by the heating/cooling unit, at a temperature of 3 to 5 deg higher than the bucket water. Each test specimen containing three electric matches was initiated by a 10-cm length of Inconel fuse wire through a built-in ignition system. Three matches were used because the heat generated by one was not sufficient to measure accurately. Both the DF N55 and ICI M103 electric matches were

tested under two different conditions: ambient pressure (without oxygen added) and with 30 psi of oxygen added. Each specimen was weighed before and after testing. The gross heat of combustion of each specimen (three matches) generated from the system was calculated by the following equation:

$$H = ((T*W) - f)/m$$

where

H = gross heat of combustion in calories per gram
W = energy equivalent of the calorimeter in calories per degree Celsius
f = correction for fuse in calories

The energy equivalent of the calorimeter (W) was determined by conducting three tests with a standard material, calorific grade benzoic acid, which released a known amount of energy (6318 cal/g). The standardization was accomplished with 300 psi of oxygen added to the bomb. Unlike the electric match, benzoic acid does not contain its own oxidizer so that a higher oxygen pressure is required to ensure complete combustion. The fuse correction (f) is necessary to adjust the combustion energy contributed by the burned wire fuse (2.3 cal/cm) during testing.

RESULTS

Table 1 and 2 summarize the data and the results of the calculations for the ICI M103 and the DF N55 Electric matches, respectively.

Table 3 summarizes the energy equivalent of the Parr 1261 bomb calorimeter.

Table 4 summarizes the gross heat of combustion for the ICI M103 electric match at ambient pressure (without added oxygen).

Table 5 summarizes the gross heat of combustion for the ICI M103 electric match with 30 psi oxygen added.

Table 6 summarizes the gross heat of combustion for the DF N55 electric match at ambient pressure (without added oxygen).

Table 7 summarizes the gross heat of combustion for the DF N55 electric match with 30 psi oxygen added

Table 8 indicates the comparative values for both matches in the closed bomb test.

Table 9 indicates the comparative values of the gross heat of combustion for both matches.

CONCLUSIONS

As shown in the tables, the tests and the calculations gave reasonable results. That is, they were consistent within a small standard deviation.

A comparison of the results in the closed bomb test (table 8) shows that the ICI M103 match generates higher peak pressure and impetus than the Davey Fire (DF) N55 match. The ICI M103 match also has a longer burn time and rise time. No question but that the ICI match is a more vigorous burning match. But the fact that the DF N55 match has been used successfully in pyro items is an indication that any candidate match with less output than the ICI match may still be used provided that the values are comparable to the values of the ICI M103 match and the DF N55 match.

Table 9 verifies the statement that the ICI M103 match is a more energetic match because the values for the gross heat of combustion is consistently higher for that match, under both test conditions, than that obtained from the DF match.

The manufacturer of the calorimeter suggests adding additional pressure into the closed bomb to insure that a test sample will burn completely. With pyrotechnic matches, the match composition has an oxidizer as an active ingredient, so the extra pressure is not needed. However, in the interest of obtaining some limited information on the effects of pressure on the match, it was decided to use 30 psi pressure as the increase after some limited tests using a range of other values. Tables 5 and 7 include the data obtained from these tests. Based on the results, this extra pressure will not be used in the future because it is difficult, without a lot of research and development type experimentation, to determine just when the match substructure begins to "burn." Consequently, the values obtained may include energy generated not only by the combustible portion of the match, but by parts holding the match together.

The two matches tested are ones that have been used successfully for many pyrotechnic items. It should be noted that the values obtained are not absolute but are relative values, i.e., if the values of a candidate match is reasonably close to the values obtained with the M103 and the DF matches, then it would appear that a closer look is warranted.

The intent of conducting these tests is to screen candidate matches with some confidence that they will perform as intended. However, these tests are not intended to substitute for actual testing with the pyro item. But if these preliminary tests can screen "good" or "bad" matches, then there can be a significant cost savings because, when compared with the calorimeter tests which are relatively inexpensive, live firing tests are very expensive. Of course, specific cost savings can not be derived at this time because the identity of the end item and type of live firing tests are not defined. These tests were the first attempt to categorize match output, so that the data base has to be expanded considerably before testing of an end item can be eliminated.

RECOMMENDATIONS

As a result of this test program, it is recommended that any new matches submitted as candidates for use in any pyrotechnic item be subjected to these two tests, as a minimum, before any full scale tests be performed on the final pyro configuration. The data obtained from the closed bomb tests will be significant because the output energy of the candidate match should be at least comparable to the ones tested if the match is to deliver hot flame/ hot gas only. The impetus test is a good measure of potential effectiveness of the match. However, if the generation of hot particles is an important part of the requirements to ignite the pyro item, then a "spitting" test should also be included in the screening process.

In addition to these tests, a function test through the Jonell Device should be performed in order to verify that the candidate matches work and can be considered as serious candidates.

If an unknown match is submitted to the U.S. Army Armament Research, Development and Engineering Center for use in a pyrotechnic item, these tests should be conducted on a representative sample of at least 25. If the results on the candidate matches are comparable to the results of the two types of matches tested (Davey Fire N55 or ICI M103), then it can be assumed that the substitute matches will ignite the pyrotechnic item and justification for testing the final pyrotechnic item with the matches can be made.

Table 1
Results of the pressure closed bomb test using ICI M103 electric matches

Test no.	Peak pressure (psi)	Rise time (ms)	Slope (psi/ms)	Impulse (psi/ms)	Impetus (ft-lb/lb)	Burn time (ms)
1	30.77	24.25	1.02	0.645	146666	37.93
2	36.32	18.69	1.55	0.618	173120	33.18
3	39.40	18.83	1.67	0.713	187801	27.38
4	45.39	21.47	1.69	0.823	216353	35.20
5	36.78	20.98	1.40	0.700	175313	35.52
6	40.07	24.79	1.29	0.730	190995	37.78
7	35.22	20.94	1.35	0.591	167877	32.36
8	33.32	23.86	1.12	0.717	158821	38.31
9	38.68	20.65	1.50	0.566	184369	33.89
10	35.16	19.99	1.41	0.523	167591	30.79
11	41.10	19.50	1.69	0.616	195904	30.40
12	35.42	23.13	1.23	0.729	168830	39.48
13	41.46	20.17	1.64	0.625	197620	33.04
14	34.71	19.84	1.40	0.738	165446	36.51
15	41.04	20.27	1.62	0.709	195618	27.33
16	37.37	21.61	1.38	0.949	178125	43.84
17	38.72	23.00	1.35	0.694	184560	33.85
18	36.73	19.90	1.48	0.578	175075	33.13
19	36.81	13.16	2.24	0.788	175458	29.17
20	35.86	21.06	1.36	0.582	170928	33.70
21	40.62	17.52	1.85	0.591	193616	31.47
22	41.61	23.33	1.43	0.738	198335	37.04
23	35.07	22.28	1.26	0.593	167162	34.97
24	37.30	21.03	1.42	0.655	177792	33.05
25	37.52	23.24	1.29	0.614	178840	33.22
Average	37.70	20.94	1.47	0.673	179689	34.10
Std. Dev.	3.16	2.46	0.25	0.100	15053	3.78

The average weight of the ICI M103 electric match in grams for impetus calculation is 0.0242.

Table 2
Results of the pressure closed bomb test using DF N55 electric matches

Test no.	Peak pressure (psi)	Rise time (ms)	Slope (psi/ms)	Impulse (psi/ms)	Impetus (ft-lb/lb)	Burn time (ms)
1	25.23	14.76	1.37	0.664	90946	32.36
2	34.97	12.05	2.32	0.578	126056	22.39
3	39.87	9.04	3.53	0.527	143719	18.17
4	33.46	10.21	2.62	0.78	120613	28.45
5	38.25	9.49	3.22	0.427	137879	15.87
6	34.46	12.71	2.16	0.734	124218	27.17
7	34.73	10.42	2.67	0.59	125191	23.01
8	39.07	12.84	2.43	0.726	140821	24.97
9	33.55	17.55	1.53	0.905	120937	34.42
10	34.21	8.96	3.05	0.865	123316	30.41
11	29.95	13.86	1.73	0.717	107960	30.15
12	29.95	16.75	1.43	0.646	107960	28.38
13	27.78	18.86	1.18	0.92	100138	41.33
14	31.35	8.60	2.92	0.314	113007	14.86
15	34.51	15.03	1.84	1.134	124398	39.86
16	29.31	9.76	2.4	0.532	105653	23.19
17	31.32	9.33	2.69	0.526	112899	22.37
18	32.24	10.71	2.41	0.622	116215	24.88
19	31.87	8.76	2.91	0.426	114881	17.53
20	34.37	11.76	2.34	0.655	123893	24.86
21	33.52	8.70	3.08	0.411	120829	15.99
22	29.31	10.92	2.15	1.420	105653	56.28
23	35.57	8.80	3.25	0.443	128219	18.10
24	28.78	12.16	1.89	0.604	103743	26.60
25	30.93	8.90	2.78	0.454	111493	19.62
Average	32.74	11.64	2.4	0.66	118026	26.45
Std. Dev.	3.51	3.00	0.64	0.25	12635	9.38

The average weight of the DF N55 electric match in grams for impetus calculation is 0.032.

Table 3
Energy equivalent of the Parr 1261 bomb calorimeter using a known standard, benzoic acid, as the test material

Test no.	Weight of specimen (g)	Temperature rise (°C)	Fuse correction (cal.)	Energy equivalent (cal/g)
1	0.192	2.3221	15	537
2	0.229	2.6848	15	552
3	0.204	2.4212	15	546
Average				545

Table 4
Gross heat of combustion for ICI M103 electric matches at ambient pressure (without oxygen added)

Test no.	Weight of specimen (g)	Temperature rise (°C)	Fuse correction (cal.)	Gross heat of combustion (cal./g)
1	0.068	0.0805	8.1	526
2	0.057	0.0805	8.1	627
3	0.063	0.0917	8.1	670
4	0.059	0.0833	8.1	632
5	0.060	0.0920	6.4	613
Average				614

Table 5
Gross heat of combustion for ICI M103 electric matches with 30 psi oxygen added

Test No.	Weight of specimen (g)	Temperature rise (°C)	Fuse correction (cal.)	Gross heat of combustion (cal./g)
1	0.07	0.1358	3.5	1007
2	0.069	0.131	1.2	1018
3	0.073	0.1979	9.2	1352
Average				1126

Table 6
Gross heat of combustion for DF N55 electric matches at ambient pressure
(without oxygen added)

Test no.	Weight of specimen (g)	Temperature rise (°C)	Fuse correction (cal.)	Gross heat of combustion (cal./g)
1	0.087	0.0811	4.6	455
2	0.088	0.0824	6.0	442
3	0.087	0.0792	1.7	477
4	0.096	0.0813	8.1	377
5	0.094	0.0836	6.4	417
Average				434

Table 7
Gross heat of combustion for DF N55 electric matches with 30 psi oxygen added

Test no.	Weight of specimen (g)	Temperature rise (°C)	Fuse correction (cal.)	Gross heat of combustion (cal./g)
1	0.092	0.1593	2.9	916
2	0.107	0.115	8.1	510
3	0.095	0.1341	5.7	710
Average				712

Table 8
Comparison of pressure closed bomb test

Item	Relative peak pressure	Relative rise time	Relative slope	Relative impulse	Relative impetus	Relative burn time
ICI M103[a]	100	100	100	100	100	100
DF N55[b]	87	56	163	99	66	78

[a]The relative performance of the M103 electric match is set at a baseline value of 100.

[b]Comparison is based on the average results.

Table 9
Comparison of gross heat of combustion

Item & test conditions	Gross heat of combustion (cal/g)	Relative gross heat of combustion
ICI M103 at ambient temperatures[a]	614	100
ICI M103 w/30 psi oxygen added[a]	1126	100
DF N55 at ambient pressure[b]	434	71
DF N55 w/30 psi oxygen added[b]	712	63

[a]The relative gross heat of combustion for the M103 match is set at a baseline value of 100.

[b]Comparison is based on the average results.

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